Acoustic and Thermal Testing of an Integrated Multilayer Insulation and Broad Area Cooling Shield System

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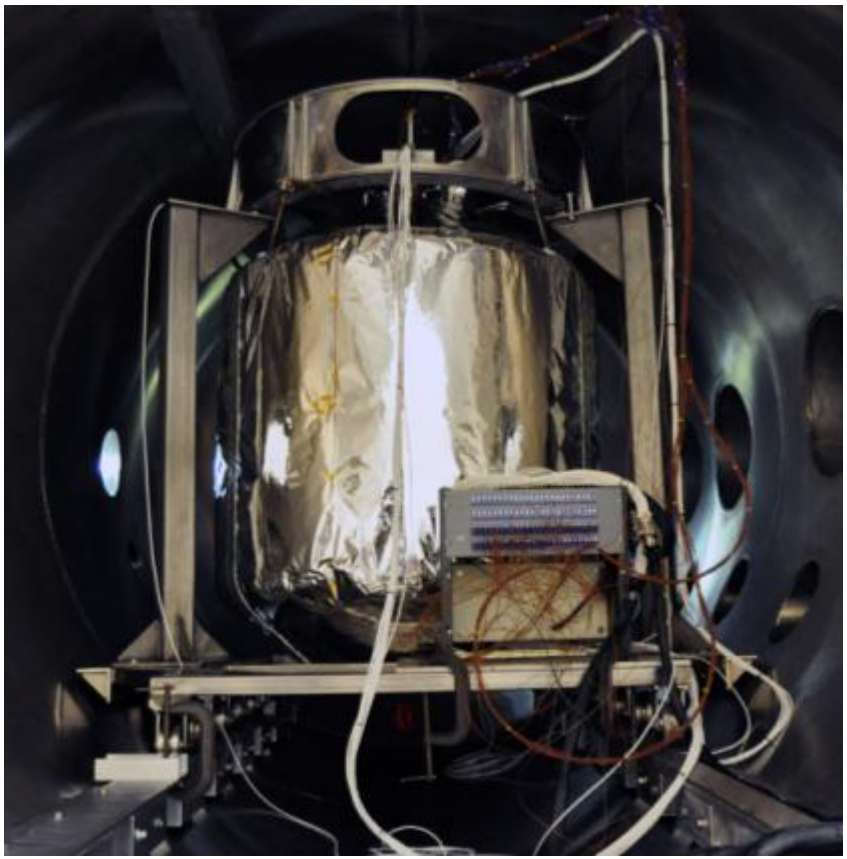
MLI/BAC Shield Thermal and Acoustic Test

Cryogenic Propellant Storage and Transfer (CPST) Technology Maturation Plan Objectives: Assess the structural performance of a Multilayer Insulation (MLI) and Broad Area Cooling (BAC) shield assembly subjected to launch acoustic loads.

- **Overview**
  - Design, fabricate, and assemble a structurally and thermally acceptable MLI/BAC shield test article
  - Install MLI/BAC shield on tank
  - Expose tank-applied MLI/BAC shield assembly to simulated launch acoustic loads
  - Compare data from thermal tests conducted before and after the acoustic test to assess possible degradation to the MLI/BAC shield system



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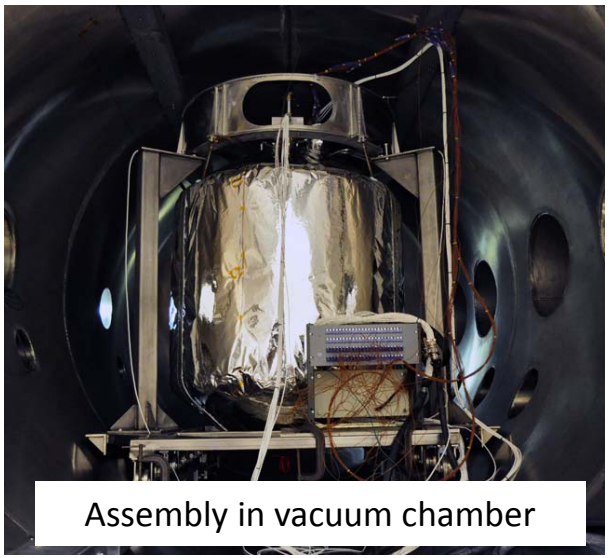
Test Approach

- **Structural (Acoustic) Test**
  - Worst-case structural load on MLI/BAC shield was desired to best evaluate structural integrity of system design. Falcon 9, Minotaur IV, Delta II and Antares (then called Taurus II) were the launch vehicles under consideration.
  - Acoustic testing was recommended by MSFC structures group for a tank-applied test for the following reasons:
    - An integrated MLI/BAC shield is relatively light weight and has a large surface area, indicating that an acoustic test will prompt a more significant response than a random-vibe test.
    - The MLI/BAC shield system responds directly to acoustic loads in contrast to smaller, heavier components that are subjected to a dynamic load that is the product of the response of the surface to which they are mounted.
- **Thermal (LN2) Test**
  - Vented Fill – top off to 97% at Steady-State
  - Steady State Heat Leak, ~95% full – BAC Shield NOT Operating
  - Steady State Heat Leak ~93% full – BAC Shield Operating at 160K +/- 10K
  - Drain Tank

The thermal test series was completed before and after the acoustic test to assess any performance degradation.

Vibro-Acoustic Test Article 1a (VATA1a) Overview

- **Tank**: 131 psi ASME Stainless Steel Pressure Vessel
  (4 ft dia, 4.6 ft high, 48.5 ft^3, 644 lbs, 66.5 ft^2, 3/16" wall thickness)
  SOFI: Formed in faceted shape to accommodate LBMLI follow-on test, thickness ranges from 0.5" – 4"
- **Integrated MLI/BAC shield system:**
  - Inner MLI blanket: 30-layer, 8 layer/cm
  - BAC shield
    - 0.25" tube bonded to 5 mil aluminum foil with Scotch-Weld 2216 epoxy
    - Chilled GN2 (~ 160K) circulated through tube loops to simulate active cooling
    - Ultem standoffs, bonded to tank, support BAC shield
  - Outer MLI blanket: 30-layer, 20 layer/cm
- **Tank Struts:** 6 Titanium tank support struts (~1" dia.)



Assembly in vacuum chamber

Ultem standoffs

Foamed tank

Inner MLI Blanket

BAC shield/tube assembly

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MSFC 4619 Acoustic Chamber

- The Acoustic Test Facility consists of a Reverberation Chamber, which is constructed of reinforced concrete.
  - Encloses 5000 ft^3.
  - Shape is approximately cubic with 17 feet per side.
  - No parallel surfaces in the room to promote a diffuse acoustic environment.
- The acoustic input is generated by four WAS 3000 Modulators with a combined acoustic power of 120 kW.
  - Maximum acoustic level is approximately 160 dB in the room's center.
- Data acquisition will consist of a Precision Filters 28000 for signal conditioning, a TEAC GX for recording, and an m+p vibration control system for analysis.

VATA1a Acoustic Test Configuration

VATA was transported from 4205 to 4619 for acoustic testing. A plastic cover was used to keep VATA MLI clean and protected.

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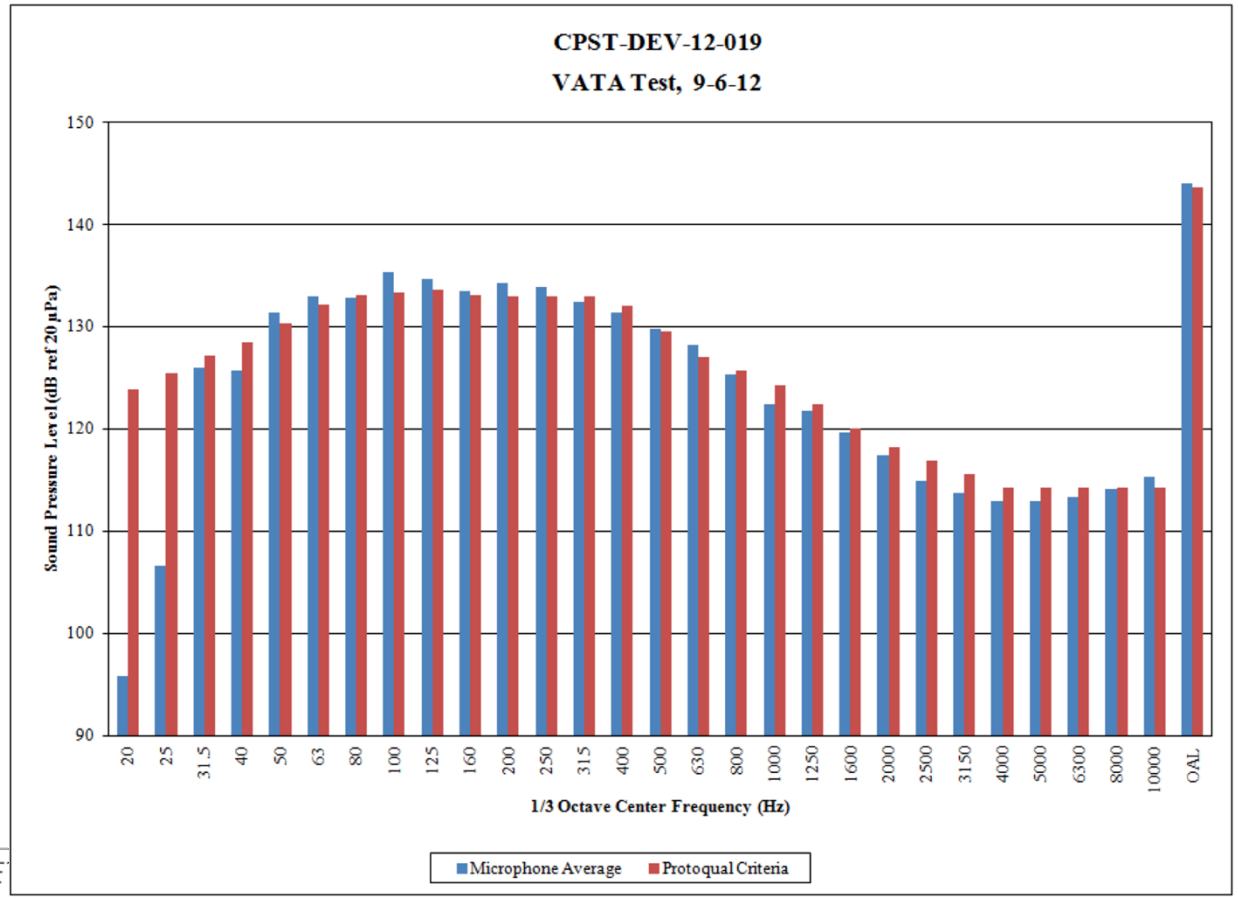
MSFC PRDL Exploration Systems Test Facility

- NASA MSFC Propulsion Research and Development Laboratory (Bld. 4205/Rm. 108)
- 9 ft diameter by 20 ft long vacuum chamber (10^{-8} torr)
- Pumps: 1 roughing (Kinny-CB7230), 2 turbos (TMG2400), 2 cryos (ADPSHD22)
- 240 kW DC power (16 supplies @ 150 V, 100 Amps)
- Control, Data Acquisition via LabVIEW, NI, and Iotech
- Liquid nitrogen (150 psig) / gaseous nitrogen (4500 psig) / Missile grade air (3500 psig)

Results Summary: VATA1a Acoustic Test Data

- Desired acoustic environment was successfully produced for test.
  - Based on NASA-STD-7001A and MLI-STD-1540
- Out-of-plane responses occurred between 1.28 and 4.81 root mean square acceleration (GRMS).
- Overall highest response occurred on Accelerometer #05, positioned on the BAC shield standoff at the VATA tank equator.
- Acceleration levels and overall profiles recorded during testing were appropriate for the applied acoustic environment.



Accelerometer	GRMS
R1R	1.941
R1L	1.82
R1T	0.904
R2R	2.695
R2L	0.772
R2T	0.48
R3R	1.278
R3L	3.55
R3T	1.178
R4R	3.359
R5R	4.806
R7L	0.911
R8L	1.648
R9R	1.928
R9L	1.774
R9T	0.847
R10R	2.142
R10L	0.49
R10T	0.477

Results Summary: VATA 1a
Passive Thermal Test Comparison

HEAT LEAK TYPE	PRE-ACOUSTIC TEST DATA	POST-ACOUSTIC TEST 2 DATA
Total Heat Leak from Load Cell Calculation	10.2 W	10.0 W
Total Heat Leak from Flow Meter Calculation	**10.7 W**	**10.8 W**
All 6 Struts	1.0 W	1.0 W
Vent Line	0.0086 W	0.0083 W
Fill/Drain Line	0.018 W	0.018 W
BAC inlet	0.0050 W	0.0049 W
BAC outlet	0.00043 W	0.00048 W
6 Bottom Standoffs	0.16 W	0.16 W
27 Side Standoffs	2.5 W	2.5 W
6 BAC inlet ullage standoffs	0.15 W	0.15 W
3 BAC outlet ullage standoffs	0.076 W	0.076 W
Silicon Diode Rake	1.3 W	1.3 W
Total Heat Leak through Penetrations	5.2 W	5.2 W
Total Heat Leak through MLI + Surf-Mounted Instr.	5.5 W	5.6 W

Results Summary: VATA 1a
Active Thermal Test Comparison

HEAT LEAK TYPE	PRE-ACOUSTIC TEST DATA	POST-ACOUSTIC TEST DATA
Total Heat Leak from Mass Calculation	6.1 W	6.0 W
Total Heat Leak from Flow Meter Calculation	**6.8 W**	**6.8 W**
All 6 Struts	1.1 W	1.1 W
Vent Line	0.012 W	0.011 W
Fill/Drain Line	0.018 W	0.018 W
BAC inlet	0.00012 W	0.00014 W
BAC outlet	0.00036 W	0.00050 W
6 Bottom Standoffs	0.084 W	0.084 W
27 Side Standoffs	0.98 W	0.97 W
6 BAC inlet ullage standoffs	0.066 W	0.066 W
3 BAC outlet ullage standoffs	0.033 W	0.033 W
Silicon Diode Rake	1.25 W	1.31 W
Total Heat Leak from Penetrations	3.51 W	3.55 W
Total Heat Leak through MLI, Surface-Mounted Instr.	3.29 W	3.25 W
Heat Removed from BAC Shield	12.9 W	12.0 W

VATA1a Thermal Test Summary

- **Pre- and Post-Acoustic Passive Thermal Steady State Tests compared:**
  - MLI temperature profiles essentially identical (Δ_{max} = 0.9K)
  - Boiloff flowmeter data essentially identical (Δ_{max} = 0.0003 ACFM)
  - Ullage stratification essentially identical (Δ_{max} = 0.01K)
  - Heat leak ~10.5 Watts
- **Pre- and Post-Acoustic Active Thermal Steady State Tests compared:**
  - BAC shield operations repeatable and reliable
  - MLI temperatures identical, cooler than for passive case (Δ_{max} = 1.7K)
  - Boil-off flow-meter data essentially identical (Δ_{max} = 0.0002 ACFM)
  - Ullage stratification nearly identical, 0.5 K shift is due to slightly different liquid level height between active thermal tests
  - Heat leak with BAC shield operating ~6.5 Watts
  - BAC shield draws ~12.5 Watts during operation
- **Thermal test series proves:**
  - Launch acoustic loads do not degrade thermal performance of MLI and BAC shield in VATA1a configuration.
  - Thermal tests can be highly repeatable, even with test article removal and transport between two thermal tests.

VATA1a Key Performance Parameters

- **Visual inspection of VATA exterior after acoustic test**
  - No damage or change was evident on the VATA exterior after the acoustic test. During the acoustic test, the only movement observed was a slight vibration of the outer MLI blanket.
- **BAC shield leak check**
  - Two BAC shield leak checks were conducted; no leaks were found:
    - Leak checker was attached to BAC tube loop, tube loop was evacuated, and helium was sprayed around exposed fittings.
    - VATA was installed in vacuum chamber, vacuum chamber was evacuated, BAC tube loop was filled with helium, and leak checker was attached to turbo pumps.
- **Acoustic test data analysis**
  - Test Sound Pressure Level (SPL) consistent with test requirements
  - Accelerometer data reasonable for test
- **Pre- and post-acoustic test LN2 thermal test data comparison**
  - Thermal test matrix was successfully conducted before and repeated after the acoustic test
  - No difference in either passive or active tests was observed between the two test iterations
- **Visual inspection of VATA thermal protection system during disassembly**
  - Minor denting observed in BAC shield; did not require repair for VATA2

VATA Series Test Matrix Highlights

completed

- **VATA 1a:** Traditional MLI, BAC shield and support standoffs
  - **Thermal Test 1: 08/14/12 thru 08/29/12**
  - **Acoustic Test: 09/06/12**
  - **Thermal Test 2: 09/12/12 thru 09/25/12**
- **VATA 1b:** Traditional MLI, no BAC shield, no support standoffs, SOFI and MLI blanket with plugs
  - **Thermal Test: 10/23/12 thru 11/05/12**
- **VATA 2a:** Inner LBMLI, BAC shield, and Outer Traditional MLI
  - **Thermal Test 1: 01/07/13 thru 01/24/13**
  - **Acoustic Test: 03/22/13**
  - **Thermal Test 2: 03/29/13 thru 04/06/13**
- **VATA2b:** Inner LBMLI, Vapor Cooled Shield, and Outer Traditional MLI
  - **Thermal Test: 05/01/13 thru 05/10/13**

in progress

- **VATA2c:** Inner LBMLI, Vapor Cooled Struts, and Outer Traditional MLI
  - **Thermal Test: In Progress**

planned

- **VATA2d:** Inner LBMLI
  - **Thermal Test: Planned**
- **VATA3a:** Traditional MLI with Interleaved Seams (Volume Matched to LBMLI)
  - **Thermal Test: Planned**
- **VATA3b:** Traditional MLI with Interleaved Seams (Mass Matched to LBMLI)
  - **Thermal Test: Planned**
- **VATA3c:** Traditional MLI with Interleaved Seams (Layer Number Matched to LBMLI)
  - **Thermal Test: Planned**

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